International Journal of
Transportation Engineering and Traffic System

ISSN: 2456-2343
Volume 11, Issue 1, 2025
January–June
DOI (Journal): 10.37628/IJTETS

https://journalspub.com/journal/ijtets/

Research IJTETS

Structural Analysis and Design Considerations for Flyover Bridges

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Abstract

Bridges serve as essential components of transportation networks, facilitating the movement of vehicles and pedestrians across obstacles, such as rivers, valleys, and roads. The stability of a bridge largely depends on the strength and structural capacity of its deck slab. The deck slab must endure both its own weight and the additional loads imposed by vehicles. A key aspect of bridge design is assessing the flexural stress acting on the deck slab to determine if additional support is necessary. When the flexural stress generated by the combined effect of the slab's self-weight and vehicular load remains within the permissible limit of the given concrete grade's flexural strength, the slab alone can support the loads, eliminating the need for girders. However, if the flexural stress surpasses the allowable strength of the concrete, girders must be introduced to provide reinforcement and prevent structural failure. The required number of girders is determined by the extent to which the flexural stress exceeds the permissible limit. This can be expressed as the ratio of the actual flexural stress of the concrete to its maximum allowable flexural strength. A greater deviation from the permissible strength indicates a higher requirement for girders to distribute the load effectively and maintain structural integrity. A thorough structural evaluation is crucial in determining the optimal number of girders to ensure the bridge can safely bear traffic loads without excessive stress on the deck slab. The strategic use of girders enhances load distribution, prolongs the service life of the bridge, and ensures long-term durability. By carefully analyzing the flexural stress and integrating girders where necessary, engineers can design more resilient bridge structures that meet safety and performance standards.

Keywords: Flexural stress of given grade of concrete, safety of foundation, load distribution, deck slab design, reinforced concrete, girder placement, traffic load assessment, bridge stability

INTRODUCTION

Flyover bridge for width of slab 16 m & spacing between piers = 9 m taken & flexural stress of given grade of concrete is found by using bending equation for a given thickness of deck slab. Flexural stress obtained is compared with flexural strength of M45 grade concrete. The flexural stress lies within permissible value of flexural strength of M45 grade concrete, hence, there is no provision to provide girder to support the deck slab [1, 2].

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Received Date: January 29, 2025
Accepted Date: January 31, 2025
Published Date: February 03, 2025

Citation: Birendra Kumar Singh. Structural Analysis and Design Considerations for Flyover Bridges. International Transportation Engineering and Traffic System. 2025; 11(1): 1–17p.

RESULTS & DISCUSSION

Length of slab = 16 m.
Spacing between pier = 10 m.
Bending of slab along shorter direction = 10 m.
Wt of slab: 16 x 10 x 0.8 x 24 = 307.20 t
Wt of vehicle:

3.5 m x 1.2 m = 70 t (class AA loading taken)

$1m^2 \quad = \quad \frac{70}{4.2}$

$10 \times 16 \quad \rightarrow \quad \frac{70 \times 10 \times 16}{4.2} = 2667\ t$

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Since the bending of the slab is involved, hence, the whole length of slab & spacing of pier are taken, i.e., whole slab is fully loaded by vehicle.

Hence, the total load on slab = 2667 + 307.20 = 2974.20 t

In Case of Pavement

3.5 m x 1.2 m = 70 t

1 m^2 = $\frac{70}{4.2}$

18 x 4 → $\frac{70\ x\ 18\ x\ 4}{4.2}\ t$,

i.e., load of one vehicle having 18 m length (long vehicle) & 4 m width of vehicle & total load found & thickness of aggregate is found by tensile strength of aggregate since upward soil pressure is acting. Hence,

thickness of aggregate $= \frac{Total\ Load}{18\ m\ x\ 1000\ x\ t} = Tensile\ strength\ of\ aggregate$ (10% of compressive strength)

Length 18 m > 4 m.

Hence, 18 m taken.

Now total load on slab = 2974.20 t

Since the lateral load because 16 m length of slab comparable to spacing of pier = 10 m.

Hence, load intensity for slab $w = \frac{2974.20}{16\ x\ 10} = 18.59\ t/m^2$

Since, the bending of slab takes place along shorter direction 10 m.

Hence, bending moment $M = \frac{18.59\ x\ (10)^2}{8} = 232\ t - m$

Using bending equation:

$$\frac{232\ x\ 1000\ x\ 10\ x\ 1000}{\frac{1}{12}\ x\ 1000\ x\ (800)^3\ x \frac{2}{800}}$$

$$\frac{2320000000}{106666667} = 22 N/mm^2 > 13 N/mm^2$$

Hence, the depth of slab is increased by 900 mm so that we get flexural stress within limit (M40 grade concrete) so that we do not need girder to support slab.

Hence, $\frac{2320000000}{\frac{1}{12}\ x\ 1000\ x\ (900)^3\ x \frac{2}{900}}$

$= \frac{2320000000}{135000000} = 17 N/mm^2$ (M 50 grade concrete taken)

Beam or girder is not needed to support slab if flexural stress lies within permissible limit.

If flexural stress of concrete for slab is more than permissible value, we need girder to support the slab.

Spacing between pier = 9 m taken.

In that case, the load for class AA loading.

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3.5 m x 1.2 m = 70 t

1m^2 $\rightarrow \frac{70}{4.2}$

16 x 9 $\rightarrow$ $\frac{70\ x\ 16\ x\ 9}{4.2} = 2400\ t$

Wt of slab: 16 x 9 x 0.90 x 24 = 311 t.

Hence, total load on slab = 2400 + 317 = 2711 t
w = Load intensity since lateral load:

$$w = \frac{2711}{16\ x\ 9} = \frac{2711}{144} = 18.83\ t/m^2$$

$M = \frac{18.83\ x\ (9)^2}{8} = 190.65\ t - m$ [Bending along shorter direction of slab takes place]

Hence, 9 m taken for horizontal member.

In case of vertical member, like in column or pier ht of column, is bending, hence, l = ht of column takes to find B.M. in $M = \frac{wl^2}{8}$.

Using bending equation: $\frac{190.65\ x\ 1000\ x\ 10\ x\ 1000}{\frac{1}{12}\ x\ 1000\ x\ (900)^3\ x\frac{2}{900}}$.

Hence, $\frac{1906500000}{135000000}$ = 14 N/mm^2

[M45 grade concrete is used]

It is within permissible limit, hence, no need to provide a girder.

Hence, the slab will be put on abutment itself no girder is used.

If spacing between piers is 13 m or 14 m which is much more in that case flexural stress of slab is more than its permissible value of flexural strength of given grade of concrete in that case girder will be used [3, 4].

No of girders: flexural stress of given grade of concrete found by using bending equation where spacing between pier is 13 m or 14 m.

No of girders concrete = $\frac{\text{flexural stress of concrete}}{Flexural\ strength\ (permissible)\ for\ given\ grade\ of\ concrete}$.

Since flexural stress obtained by using bending equation is less than permissible flexural strength of M45 grade concrete, hence, no provision of girder. Hence, the slab is resting directly on the pier.

Load on pier of flyover bridge = 2711 tons cross sectional area required since direct stress because upward reaction is acting designed for permissible compressive stress σcc.

Thickness of pier required:

Lateral load: $0.271\ x\ 2711 = \left[\frac{1-Sin\varphi}{1+Sin\varphi} = 0.271, \varphi = 35^o\right]$ = 735 t acting on 1 m width of pier & ht of pier = 6 m since dimensions are comparable to each other, hence, it is the case of lateral load. Hence, load intensity:

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$$w = \frac{735}{1 \ x \ 6} = 123 \ t/m^2$$

The height of the pier is bending. In case of vertical member bending takes place along height of vertical member whereas in horizontal member, like slab bending, takes place along shorter direction of slab.

Hence, bending moment $M = \frac{123 \ x \ (6)^2}{8} = 554 \ t - m$

Using bending equation:

$$\frac{M}{Z} = \sigma cbc$$

$\frac{554 \ x \ 1000 \ x \ 10 \ x \ 1000}{\frac{1}{12} \ x \ 1000 \ x \rightleftarrows d^3 \ x \ \frac{2}{d}} = 15$ [M45 grade concrete]

$2500 \ d^2 = 5540000000$
$d^2 = 2216000$
d = 1.489 meter.
Hence, cross sectional area of column 1 m x 1.489 meters taken.

Wt of pier:

1 x 1.489 x 6 x 24 = 21.44 t,

where cross-sectional area of column is 1m x 1.489 m.

6m = Height of pier

24 N/m^2 = unit wt of concrete

Hence, total load of pier:

2711 + 21.44 = 2732.44 t

10% wt of foundation = $\frac{10}{100} \ x \ 2732.44 = 273.24 \ t$

Foundation

Total load at foundation base = 2732.44 + 273.24 = 3006 t

Since load is much more, hence, mat foundation is provided, i.e., R.C.C slab at required depth of foundation.

Lateral load at foundation base = 0.271 x 3006 = 815 t

Hence, we require rocky strata which bears capacity = 300 t/m^2 since 815 t < 300 t/m^2 (Bearing capacity of rocky strata), hence, mat foundation is required.

Hence, foundation base size required $= \frac{3006}{300} = 10m^2$

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If the width of foundation base is 2 m, hence, 5 m length of the foundation base is required.

Load intensity $q = \frac{3006}{100} = 300\ t/m^2$

Hence, the depth of foundation required $D_f = \frac{300}{1.85}\ x\ 0.111 = 18\ meter$

Hence, at the depth of foundation 18 m R.C.C slab is provided.

For bearing capacity of soil or strength of soil load intensity taken, i.e., load at foundation $\frac{Base}{Base\ area}$ because soil has less strength as compared to stone, hence, in case of soil load intensity taken and it is compared with strength of soil but in case of stone strength of stone is compared to load in ton.

But for bearing capacity of soil lateral load in ton found & bearing capacity of soil in t/m^2 found is equal to load in ton because it is not vertical load. For vertical load, load intensity is found which will be less than bearing capacity of soil in t/m^2.

Depth of mat foundation (R.C.C. slab): Since upward soil pressure is acting, hence, thickness of mat foundation base found by tensile strength of given grade of concrete.

Hence, $\frac{3006\ x\ 1000\ x\ 10}{5000\ x\ t} = \frac{10}{100}\ x\ 45 = 4.5$ [5m = length of foundation base]

22500 t = 30060000

t = 1.34 meters.

For determining the depth of pier using bending equation we found d = 1.45 meter & width = 1 m. Hence, cross sectional area 1 m x 1.45 m taken for pier.

Now, the lateral load at foundation base = 0.271 x 30006 = 815 t

where $\frac{1-Sin\varphi}{1+Sin\varphi} = 0.271$ [ϕ = 35o for concrete]

This lateral load 815 t = vertical load acting tangentially along length of foundation base slab = 5 m & thickness 1.34 m.

Hence, shear stress = $\frac{815\ x\ 1000}{500\ x\ 134} = \frac{815000}{67000} = 12\ Kg/cm^2$.

Shear strength of surrounding soil in base of foundation having strength 300 t/m^2 = shear strength of soil = bending strength because soil has less strength compared with stone, etc.

Now, the strength of soil at foundation base = $\frac{300\ x\ 1000}{100\ x\ 100} = 30\ Kg/cm^2$.

Hence, safe.

Now load acting at foundation base = 3006 t [Action = Reaction].

Hence, upward reaction = 3006 t acting along 18 m depth of foundation & 1m width of pier tangentially, hence, shear stress $= \frac{3006\ x\ 1000}{1800\ x\ 100} = 16.7\ Kg/cm^2$

Average strength of soil = $\frac{20\ +\ 300}{2} = 160\ t/m^2$.

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(Average strength of top strata soil & bottom strata is taken)

$160\ t/m^2 = \frac{160\ x\ 1000}{100\ x\ 100} = 16\ Kg/cm^2 \approx$ 16.7 Kg/cm^2.

Hence, the depth of foundation & foundation base size is correctly taken for safety of foundation.

Since distance between pier (9 m taken), hence, lateral distance $\frac{9}{2}$ = 4.5 m taken for both piers.

Since, the lateral load at base of foundation 0.271 x 3006 = 815 t should be balanced by lateral strength of soil of lateral distance 4.5 m & 2 m.

Hence, lateral strength of soil = 4.5 x 2 x 300 [2 m width of foundation base]

= 2700 t > 815 t, hence, O.K.

Similarly, = 4.5 x 5 x 300 (5m length of foundation base slab)

= 6750 t > 815 t

Hence, O.K.

Also check for lateral distance of 4.5 m & thickness of foundation base slab = 1.34 m.

Lateral strength of soil 300 x 4.5 x 1.34 = 1809 t > 815 t, hence, thickness of foundation base slab, size of foundation also spacing between piers are correctly taken.

Since for two piers depth of foundation, bearing capacity of soil are same, hence, it is not checked for settlement.

In column of building:
Load on column = 120 t

Self wt of column = 0.6 x 0.6 x 4 x 24 = 3.46 t.

where 0.6 m x 0.6 m cross sectional area of column 4 m = ht, 24 KN/m^3 = unit wt of concrete.

Total load = 120 + 3.46 = 123.46 t

10% wt of foundation:

$$\frac{10}{100}\ x\ 123.46 = 12.346\ t$$

Load at foundation base = 135.81 t

Lateral load at base of foundation = 0.271 x 135.81 = 37 t, hence, bearing capacity of soil needed = 40 t/m^2 > 37 t, i.e., gravel bed soil.

Foundation base size $= \frac{135.81}{40} = 3.40\ m^2$

Hence, foundation base size = 1.844 m x 1.844 m.

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International Journal of Transportation Engineering and Traffic System
Volume 11, Issue 1
ISSN: 2456-2343

Thickness of foundation base = $\frac{135.81\ x\ 1000\ x\ 10}{1.844\ x\ 1000\ x\ t} = \frac{10}{100} x\ 30$ (M30 grade concrete taken)

5532 t = 1358100

t = 245 mm

For Safety of Foundation

Lateral load at foundation base = 37 t acting vertically along 245 mm thickness & 1.844 m length of foundation base shear stress

$$= \frac{37\ x\ 1000}{184.40\ x\ 24.50} = \frac{37000}{4518} = 8\ Kg/cm^2 > 4\ Kg/cm^2$$

Hence, soil stabilization is needed.

Also 136 t acting vertically along found depth & width of column.

$$D_f = \frac{40}{1.85}\ x\ 0.111 = 2.40\ meter$$

[Since load intensity 36 t/m^2, i.e., $\frac{136}{1.844\ x\ 1.844} = \frac{136}{3.40} = 40\ t/m^2$

Hence, shear stress $= \frac{136\ x\ 1000}{2.40\ x\ 100\ x\ 0.6\ x\ 100} = \frac{136000}{240\ x\ 60} = \frac{136000}{14400}$

= 9.44 Kg/cm^2 > 4 Kg/cm^2

Hence, in foundation soil stabilization 1 part gravel & 2 parts stone particle having

$\frac{40\ +\ 2\ x\ 165}{2} = 185\ t/m^2$
= 18.5 Kg/cm2 shear stress, hence, O.K.

Now distance, i.e., spacing between columns 4 m taken.

Hence, 2 m lateral distance for one column & 2 m lateral distance for another column taken.

Lateral strength of soil = 2 x 1.844 x 40 = 148 t > 36 t (Lateral load at base, hence, O.K.).

For thickness of foundation base slab 0.245 m
Lateral strength = 2 x 0.245 x 40 = 20 t < 36 t not safe.
If 3 m width of base foundation & 0.4 m thickness of base slab
Lateral strength 3 x 0.4 x 40 = 48 t > 36 t

Hence, safety of foundation for base slab is checked.

Since foundation depth, bearing capacity for building is the same, hence, no settlement.

If the depth of foundation is different for two building also bearing capacity is different & lateral distance between two buildings for residential building up to 3 story lateral distance between two buildings less than 3m from settlement point of view it will be O.K.

But for more story (tall story) lateral distance between two buildings less than 8 m [common settlement taken] settlement → change in bearing capacity x change in foundation depth x 3.62 x 10^{-2} in cm found:

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m_v = soil depending upon voids = 3.62 x 10^{-2} taken.

If the lateral distance between two buildings is more than 10 m individual settlement for building is taken.

PIER IN RIVER

Depth of water in river above bed level of river 12 m.

Top soil: Penetration of water below bed level of river = 0.6 x 12 = 7.2 meter in which saturated depth of soil $= \frac{16}{100}\ x$ 12= 1.92 m depth of soil will be in saturated state for which bearing capacity is lowered by 50% & remaining depth of soil = 7.2 –1.92 = 5.28 m depth of soil will be in moist condition for which bearing capacity is lowered by 25%.

Bearing capacity of soil at 1.92 m depth = 1.85 x 1.92 x 9 = 32 t/m^2.

[Using $q\ =\ \gamma D\ \left(\frac{1-Sin\varphi}{1+Sin\varphi}\right)^2$] $\phi = 30^o$

[Since 1.92 m depth is in saturated state]

Since saturation 50% bearing capacity is lowered, hence, reduction in baring capacity = $\frac{32}{2} = 16\ t/m^2$.

For 5.28 m depth of soil bearing capacity = 1.85 x 5.28 x 9 = 88 t/m^2 since reduction in bearing capacity 25%.

$\frac{25}{100}\ x\ 88\ =\ 22\ t/m^2$ [Reduction].

Hence, for topsoil reduction in baring capacity = 22 + 16 = 38 t/m^2.

Since due to seeping of water below bed level river soil will be in saturated & moist state. Suppose depth of saturated soil + moist soil, i.e., penetration bottom soil

= 0.6 x 12 = 7.2 meters

In the foundation bed rocky strata water absorption 2%.

Hence, saturated depth of soil $\frac{2}{100}\ x\ 7.2\ =\ 0.144m$ [Saturated state].

Depth of rocky strata at bottom

300 = 2.6 x D x $\left(\frac{1-Sin35^o}{1+Sin35^o}\right)^2$]

= 2.6 x D x $\left(\frac{1.574}{0.426}\right)^2$]

= 2.6 x D x 14 = 36.40 D

D = 8.24 m depth of soil has rocky strata in which 0.144 m depth is in saturated state.

For 16% (soil) water absorption reduction in bearing capacity = 50%.

1 $\rightarrow$ $\frac{50}{16}$

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2% → (For rocky strata) $\frac{50 x 2}{16} = 6.25\%$

Hence, reduction in bearing capacity of rocky strata

$$= 300 - \frac{6.25}{100}\ x\ 300$$

= 300 – 18.75 = 281.25 t/m^2 [Available bearing capacity of rocky strata]

Since depth of penetration of water = 7.2 m in which 0.144 m is in saturated state, hence, remaining depth will be in moist condition, i.e., 7.2 – 0.144 = 7.056 m.

The depth of rocky strata is in moist condition.

For 16% absorption of water in soil for moist condition 25% bearing capacity is less
1 → $\frac{25}{16}$
2% → $\frac{25 x 2}{16} = 3.125\%$

Hence, for rocky strata of moist condition reduction in bearing capacity

$= \frac{3.125}{100}\ x\ 300$ = 9.375 t/m^2 reduction.

Total reduction in bearing capacity for topsoil = 16 + 22 = 38 t/m^2

For bottom strata reduction in bearing capacity 18.75 + 9.375 = 28.125 t/m^2.

Hence, total reduction in bearing capacity of soil 38 + 28.125 = 66 t/m^2.

Hence, for this much reduction available bearing capacity of soil = 300 – 66 = 234 t/m^2.

We require 300 t/m^2 bearing capacity of soil but available bearing capacity of soil 234 t/m^2. Hence, settlement occurs.

Change in pressure = 300 – 234 = 66 t/m^2

$$= \frac{66\ x\ 1000}{100\ x\ 100} = 6.6\ Kg/cm^2$$

For 300 t/m^2 bearing capacity of soil depth of foundation = 20 m
1 → $\frac{20}{300}$

234 t/m^2→ $\frac{20 x 234}{300} = 15.60\ meter$

Hence, change in depth of foundation:

ΔH = 20 – 15.60 = 4.40 meter.

Soil properties depending upon voids = 2 x 10^{-2} for sandy soil

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$m_v = 3.62 \times 10^{-2}$

For rocky = 2×10^{-2} taken.
Hence, the amount of settlement

If = $6.6 \times 4.40 \times 100 \times 2 \times 10^{-2}$
$= 6.6 \times 4.40 \times 100 \times \frac{2}{100}$
= 58 cm = 580 mm.

Much more than permissible value of settlement 50 mm.

Hence, we must provide more depth of foundation for reduction in bearing capacity of 66 t/m^2

More D_f required

$D_f = \frac{66}{1.85}\ x\ 0.111$ $\left(\frac{1-Sin\varphi}{1+Sin\varphi}\right)^2$
γ = Unit wt of soil = 1.85 t/m^3 taken $\phi = 30^o = 0.111$

Hence, D_f = 4 m

Hence, for reduction in bearing capacity of soil due to saturated & moist condition due to penetration of water 66 t/m^2 is reduction in bearing capacity of soil due to this reduction in bearing capacity of soil more settlement occurs, hence, we have to provide more depth of foundation for reduction in bearing capacity of 66 t/m^2, i.e., more depth of foundation needed = 4 m, hence, we have to provide 20 + 4 = 24 m depth of foundation [5–7].

Bearing capacity of soil for 4 m more depth of foundation

q = 1.85 x 4 x 9 = 66.60 t/m^2
γ = 1.85 t/m^3 $\left(\frac{1-Sin\varphi}{1+Sin\varphi}\right)^2 = 9\ , \varphi = 30^o$

Hence, by providing 4 m depth of foundation more we achieved the required bearing capacity of soil, hence, there will be no settlement.

PIER OF BRIDGE

Load on pier = 3000 t
Wt of pier = 1.5 x 1.5 x 7 x 24 = 37.80 t
Cross section of pier = 1.5 m x 1.5 m taken 7 m = Height of pier above ground level 24 KN/m^3 = Unit wt of concrete
Load of pier at ground level = 3000 + 37.80 = 3037 = 3037.80 t
10% wt of foundation below ground level $= \frac{10}{100}\ x\ 3037.80\ =\ 303.78\ t$
Hence, load at foundation base = 3037.80 + 303.78 = 3341.58 t
Lateral load: $\frac{1-Sin\varphi}{1+Sin\varphi}\ x\ 3341.58$

= 0.217 x 3341.58 [$\phi = 40^o$ for concrete taken]
= 725 ton.

Hence, we require the bearing capacity of soil:

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ISSN: 2456-2343

$$\frac{20 + 725}{2} = 373\ t/m^2$$

20 t/m^2 = Bearing capacity of top strata of soil & 725 t/m^2 = bearing capacity of soil at foundation base.

Suppose depth of foundation = 20 m

Hence, at depth of $\frac{20}{2} = 10\ m$lateral load of 725 tons taken (which is lateral load at base]

Bearing capacity of soil at depth = 10 m

q = Bearing capacity of soil in t/m^2
q = 1.85 x 10 x 9 = 167 t/m^2
where 10 m of soil below G.L. $\left[\frac{1-Sin\varphi}{1+Sin\varphi}\right]^2 = 9\ [\varphi = 30^o]$
γ = 1.85 t/m^3 = unit wt of soil.

Since we require 725 t/m^2 bearing capacity of soil to take the lateral load 725 t.

Hence, soil should be stabilized by 1 part gravel & 4 parts stone particles properly mixed provided surrounding the pier below ground level.

Hence, strength of soil stabilized soil below ground level surrounding the pier

$$= \frac{40 + 4\ x\ 165}{2} = 350\ t/m^2 < 725\ t$$

Hence, stone particles of strength 6 parts of bearing capacity 330 t/m^2 & 1 part gravel are properly mixed & provided surrounding the pier $= \frac{40\ x\ 6\ x\ 330}{2} = 1010\ t/m^2 > 725\ t.$

Hence, safe.
Hence, for safety of foundation 1 part gravel & 6 parts stone particles (having bearing capacity 330 t/m^2 properly mixed & provided surrounding the pier to sustain 725 t (lateral load).

Load of pier at ground level: 3037.80 t.

Load of pier below ground level 1.5 x 1.5 x 20 x 24 = 108 t [1.5 m x 1.5 m = cross section of pier 20 m = Depth of foundation, 24 KN/m^3 = Unit wt of concrete]

Hence, the total load of pier below G.L. = 3037.80 + 108 = 3146 t.

Hence, lateral load acting on pier below G.L = 0.217 x 3146 at $\frac{20}{2} = 10\ m$
= 683 t

where 0.217 $= \frac{1-Sin\varphi}{1+Sin\varphi}\ [\varphi = 40^o\ taken\ for\ concrete]$

Hence, we require bearing strength of soil surrounding the pier ≈ 700 t.

Hence 725 t taken & stabilized soil should have 1 part gravel & 6 parts stone particles having 330 t/m^2 bearing strength to sustain the lateral load acting on pier.

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Hence lateral load at foundation base in pier or column found by $\frac{1-Sin\varphi}{1+Sin\varphi}$ x vertical load at foundation base $\phi = 35^o$ or 40^o taken.

The surrounding soil around pier or column should have bearing strength at least equal to lateral load at foundation base to sustain the lateral load of pier & column.

If the bearing capacity of soil below G.L. is less than the lateral load at foundation base soil is stabilized by gravel & stone particles & this soil will be surrounding the pier or column throughout the depth of foundation to sustain the lateral load at foundation base of pier or column.

Lateral load at foundation base 125 t & if bearing capacity of soil at foundation base 300 t/m^2 available for rocky strata which is less than 725 t, hence, mat foundation is provided because we need 725 t/m^2 bearing capacity of soil but available bearing capacity of soil at foundation base 300 t/m^2, hence, we require more foundation base area found by total vertical load at foundation [8–9].

$= \frac{3341.58}{300}$
= 11 m^2

Taking 2 m width of foundation base length of foundation base required $= \frac{11}{2} = 5.6\ meter.$

So that it can sustain the load at foundation base.

Hence, by providing larger areas at foundation base (like mat foundation) load will be distributed over larger area & foundation base will be safe for safety of foundation [10].

But throughout the depth of foundation we require 725 t/m^2 bearing capacity to sustain the lateral load = 725 t found by $\frac{1-Sin\varphi}{1+Sin\varphi}$x load at foundation base [ϕ 35^o or 40^o taken].

Hence, we must stabilize the soil by 1 part gravel & 6 parts stone particles properly mixed & provided throughout the foundation depth & also at foundation base (surrounding soil) because surrounding soil around pier & foundation base have bearing capacity $\frac{20\ +\ 300}{2}$ = 160 t/m^2 or 20 t/m^2 = bearing strength of top strata of soil.

300 m^2 = bearing capacity of soil at foundation base (Average strength taken).

Since 725 t > 160 t/m^2 bearing capacity of soil surrounding soil in depth of foundation.

Hence soil will be stabilized by 1 part gravel & 6 parts stone particles provided throughout the depth of foundation & surrounding soil near base of foundation so that it can sustain the lateral load at foundation base.

Depth of penetration in the bottom soil takes place due to seeping of water below bed level of river. For 16% water absorption factor 0.6 for penetration of water.
1 → $\frac{0.6}{16}$
2% → $\frac{0.6\ x\ 2}{16} = 0.075$

Since, the depth of water below bed level of river = 12 m also.

Hence, for bottom soil penetration of water 0.075 x 12 = 0.9 meter in which saturated depth of soil $= \frac{2}{100}\ x\ 0.9 = 0.018\ meter$.

For which reduction in bearing capacity is for 16% water absorption reduction in bearing capacity of soil 50%.

$1 \rightarrow \frac{50}{16}$

2% $\rightarrow$ $\frac{50\ x\ 2}{16} = 6.25\%$

Hence, 6.25% reduction in bearing capacity of bottom strata is $\frac{6.25}{100}\ x\ 300$ = 18.75 t/m^2
[300 t/m^2 bearing capacity of bottom strata soil].
[Reduction in bearing capacity for rocky strata].

Hence, available bearing capacity = 300 – 18.75 = 281.25 t/m^2

Hence, change in pressure = 300 – 281.25 = 18.75 t/m^2

$$\frac{18.75\ x\ 1000}{100\ x\ 100} = 1.88Kg/cm^2$$

For 300 t/m^2 depth of foundation 20 m

1 $\rightarrow$ $\frac{20}{300}$

281.25 $\rightarrow$ $\frac{20\ x\ 281.25}{300} = 18.75\ meter$

Hence, change in depth = 20 18.75 = 1.25 m

Hence, settlement 1.88 x 1.25 x 100 x $\frac{2}{100}$

= 47 mm for saturated bottom strata.

[For rocky strata soil properties depending upon voids = 2 x 10^{-2} taken].

Since, the depth of penetration in soil 0.9 m in which 0.018 m is depth of saturated soil, hence, moist soil = 0.9–0.018 = 0.882 m depth of moist soil (Rocky strata)

For 16% water absorption for moist soil bearing capacity is reduced by 25%.

1 $\rightarrow$ $\frac{25}{16}$

2% $\rightarrow$ $\frac{25\ x\ 2}{16} = 3.125\%$ reduction in bearing capacity

(Water absorption for rocky strata)

Hence, reduction in bearing capacity of soil $\frac{3.125}{100}\ x\ 300 = 9.375\ t/m^2$

Hence, available bearing capacity = 300–9.375 = 291 t/m^2.

Hence, change in pressure

300 – 291 = 9 t/m^2

$= \frac{9\ x\ 1000}{100\ x\ 100} = 0.9\ Kg/cm^2$

For 300 t/m^2 depth = 20 m

1 $\rightarrow$ $\frac{20}{300}$

291 t/m^2 $\rightarrow$ $\frac{20\ x\ 291}{300} = 19.4\ meter$

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Hence, change in depth = 20 – 19.4 = 0.6 m
Hence, settlement for moist rocky strata

0.9 x 0.6 x 100 x $\frac{2}{100}$ = 11 mm.

Hence, total settlement for top strata of soil & bottom strata of soil = 730 + 47 +11
= 788 mm > 50 mm

Hence, we must provide more depth of foundation for reduced bearing capacity of soil
Total reduction in bearing capacity of soil

= 45 t/m^2 (For top strata of soil) + 18.75 + 9.375 = 73.125 t/m^2 reduction in bearing capacity of soil for top & bottom strata.

Unit wt of top strata = 1.85 t/m^3
Bottom strata = 2.4 t/m^2

$$\varphi = \frac{30^o \ + 40^o}{2} \ = \ 35^o$$

Hence, more depth of foundation needed so that failure of foundation will not take place due to this huge amount of settlement
More D_f required = $\frac{73.125}{2.4} \ x \ 0.073$ depth of foundation = 2.234 meter more needed.

Depth of foundation for pier in river 20 + 2.234 = 22.234 m taking settlement of soil into consideration.

Top strata soil: Having bearing capacity 20 t/m^2 & factor for penetration of water = 0.6 taken.

Depth of water in river = 12 m.

Hence, depth of penetration 0.6 x 12 = 7.2 meter.

Topsoil absorption of water 16%.

$\frac{16}{100} \ x \ 7.2$ = 1.152-meter depth of soil will be in saturated state & remaining soil will be in moist conditions, i.e., 7.2 – 1.152 = 6.048 m.

For saturated state soil bearing capacity is reduced by 50% & bottom soil is rocky strata water absorption 2%.

For rocky strata:
For 16% water absorption in moist condition 25% reduction in baring of capacity.

1 → $\frac{25}{16}$

2% → $\frac{25 \ x \ 2}{16} \ = \ 3.125\%$ reduction in bearing capacity for bottom strata.

SETTLEMENT

For 1.152-meter saturated state bearing capacity is reduced by 50%, i.e., available bearing capacity = 10 t/m^2.

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Change in pressure for saturated state

20–10 = 10 t/m^2 = $\frac{10\ x\ 100}{100\ x\ 100}\ =\ 1\ Kg/cm^2$

For 20 t/m2 depth → 1.152 m

1 → $\frac{1.152}{20}$

(20–10) → $\frac{1.152\ x\ 10}{20}\ =\ 0.576\ meter$

Hence, change in depth = 1.152 – 0.576 = 0.576 m

Hence, settlement for saturated soil 1 x 0.576 x 100 x $\frac{3.62}{100}\ =\ 20\ m$

Now we go from top strata to bottom strata. (Rocky strata)

Bearing capacity of soil

q = 1.85 x 7.2 x 9 = 120 t/m^2 Unit wt of top strata taken

Unit wt = 1.85 t/m^3

Reduction in baring capacity = 3.125%

$\frac{3.125}{100}\ x\ 120\ =\ 3.75\ t/m^2$ $\left[\frac{1-Sin\varphi}{1+Sin\varphi}\right]^2\ =\ 9$

$\phi = 30^o$

Available bearing capacity = 120–3.75 = 116.25 t/m^2

Hence, change in pressure = 120–116.25 = 3.75 t/m^2

$$=\frac{3.125\ x\ 1000}{100\ x\ 100}\ =\ 0.375\ Kg/cm^2$$

For 120 t/m^2 = depth 7.2 m

1 → $\frac{7.2}{120}$

116.25 → $\frac{7.2\ x\ 116.25}{120}\ =\ 6.975\ meter$

Change in depth of foundation 7.2 – 6.975 = 0.225 m

Hence, settlement for moist condition of soil

= 0.375 x 0.225 x 100 x $\frac{3.62}{100}\ =\ 3\ mm$

Hence, for top strata soil total settlement 23 mm (20 mm + 3 mm)

For saturates soil for moist soil

For bottom (Rocky strata)

Settlement 47 + 11 mm

Hence, total settlement = 23 + 47 + 11 = 81 mm > 50 mm

Not safe.

Total reduction in baring capacity

= 10 + 3.75 + 18.75 + 9.375

For top strata For bottom strata

= 42 t/m^2

Unit wt of top strata = 1.85 t/m^3

Bottom strata = 2.4 t/m^3

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$$\varphi = \frac{30^o + 40^o}{2} = 35^o$$

Average unit wt = $\frac{1.85 \ x \ 2.4}{2} = 2.12 \ t/m^3$

Hence, more depth of foundation needed taking settlement into consideration

$D_f = \frac{42}{2.12} \ x \ 0.073 = 1.45 \ m$ more depth of foundation needed.

Where unit wt of soil = 2.12 t/m^3

ϕ = 35^o taken $\left[\frac{1-Sin\varphi}{1+Sin\varphi}\right]^2 = 0.073$

Hence, the total depth of foundation = 20 + 1.45 = 21.45 meters, i.e., 22 m needed.

CONCLUSIONS

Flexural stress of deck slab is found due to load of vehicle & slab acting on it by using flexural strength of given grade of concrete if flexural stress obtained is within permissible value of flexural strength of given grade of concrete. No need for a girder to support deck slab. Also, safety of foundation is considered.

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APPENDIX

Notation

D_f	=	Depth of foundation in meter.
q	=	Load intensity in t/m^2.
γ	=	Unit wt of soil in t/m^3.
ϕ	=	Angle of repose in degree.